(2)

# REPORT DOCUMENTATION PAGE

DTIC FILE COPY

Form Approved
OMB No. 0704-0188



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**

**3. REPORT TYPE AND DATES COVERED**
Final Report 15 Jan 87-14 Feb 90

**4. TITLE AND SUBTITLE**
Phase Sensitive Amplification with SIS Mixers

**5. FUNDING NUMBERS**
AFOSR-87-0131

**6. AUTHOR(S)**
Dr Bocko

AD-A229 031

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
UNIV OF ROCHESTER
ROCHESTER, NY 14627

**8. PERFORMING ORGANIZATION REPORT NUMBER**
AFOSR-TR- 90 1096

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
AFOSR/NE
BLDG 410
BOLLING AFB DC 20332-6448

HAROLD WEINSTOCK

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
2305/C3

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
UNLIMITED

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

SEE REPORT FOR ABSTRACT

DTIC
ELECTE
NOV 16 1990
S B D

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

**14. SUBJECT TERMS**

**15. NUMBER OF PAGES**

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

# Final Technical Report

## AFOSR-87-0131

## "Phase-Sensitive Detection with SIS Mixers"

Mark F. Bocko
Department of Electrical Engineering
University of Rochester
Rochester, New York

### A) Theoretical Accomplishments

The first goal we achieved under the contract was to develop a theory for phase sensitive quantum mixers. The existing quantum mixer theory and notation was inadequate to describe the phase sensitive phenomena which we hoped to investigate. Therefore we had to develop a formalism and the theory of phase-sensitive mixing. We started with the quantum theory of mixing as presented originally by Tucker[1] and extended its application to the case when two local oscillators, LO's, at different frequencies are used to "pump" the mixer. A new notation for keeping account of the relevant sidebands in the two-LO mixer was needed. In the original notation of Torrey and Whitmer[2] each physical frequency is represented by a phasor of either positive or negative frequency. For a conventional, single-LO, mixer it is required to keep track of three sidebands; the "signal", the intermediate frequency output,"IF" and the "image". In the conventional theory the signal and IF are represented by positive frequency phasors and the image by a negative frequency phasor. Therefore the impedance matrices which appear in the single-LO mixer theory are all 3x3. In the two-local-oscillator mixer theory there are four sidebands to account for, the

1 J.R. Tucker, "Quantum limited detection in tunnel junction mixers", IEEE J. Quantum Electron., QE-15, 1234-1258, 1979.

2 H.C. Torrey and C.A. Whitmer, Crystal Rectifiers, New York, McGraw-Hill, 1948.

"signal", "IF", and two images. Furthermore each sideband must be represented twice, by both a positive and a negative frequency phasor. The positive and negative frequencies are treated separately in the computations, which require the manipulation of 8x8 matrices. The output of the mixer is the superposition of the positive and negative phasors which represent the IF. It is the superposition of the counter rotating phasors which allows one to describe phase sensitive phenomena. The complete formal theory was presented at the 1988 Applied Superconductivity conference and the paper is attached as Appendix A.

Using our formalism for describing two-LO mixers we showed that, in the limit of low local oscillator power, a matched receiver may surpass the naive quantum limit by a factor of two. There is a simple physical reason for this improvement. Each pump converts signal power to the IF as well as noise power from the nearby, (in frequency) image port. The two pumps coherently convert the same signal to the IF but the noise is the incoherent sum of the uncorrelated fluctuations at the two distinct image frequencies. The coherent sum for the signal and the incoherent sum of the image noise differ by the factor of two. This calculation is summarized in another paper which was presented at the 1988 Applied Superconductivity Conference. A reprint of this paper appears as Appendix B of this proposal.

The improvement over the conventional mixer noise in the low LO power limiting case described above is modest. Preliminary numerical investigations indicate that larger improvement may be achievable for other choices of parameters.

In general the new conclusions which we have been able to draw from our theoretical analysis is that if a "well matched" mixer is biased so that it appears as a purely resistive device the noise improvement is only a factor of two. By well matched we mean that the reflection coefficient at the signal port is zero and that the image ports are shorted so that the reflection coefficient is unity. However it appears that if the mixer is biased so that it appears reactive there may be an even greater reduction of the noise. The reduction of the noise can be greatest if the signal port is poorly matched.

Thus the two-LO technique may be a useful technique to improve the noise of intrinsically mismatched receivers.

**B) Experimental Accomplishments**

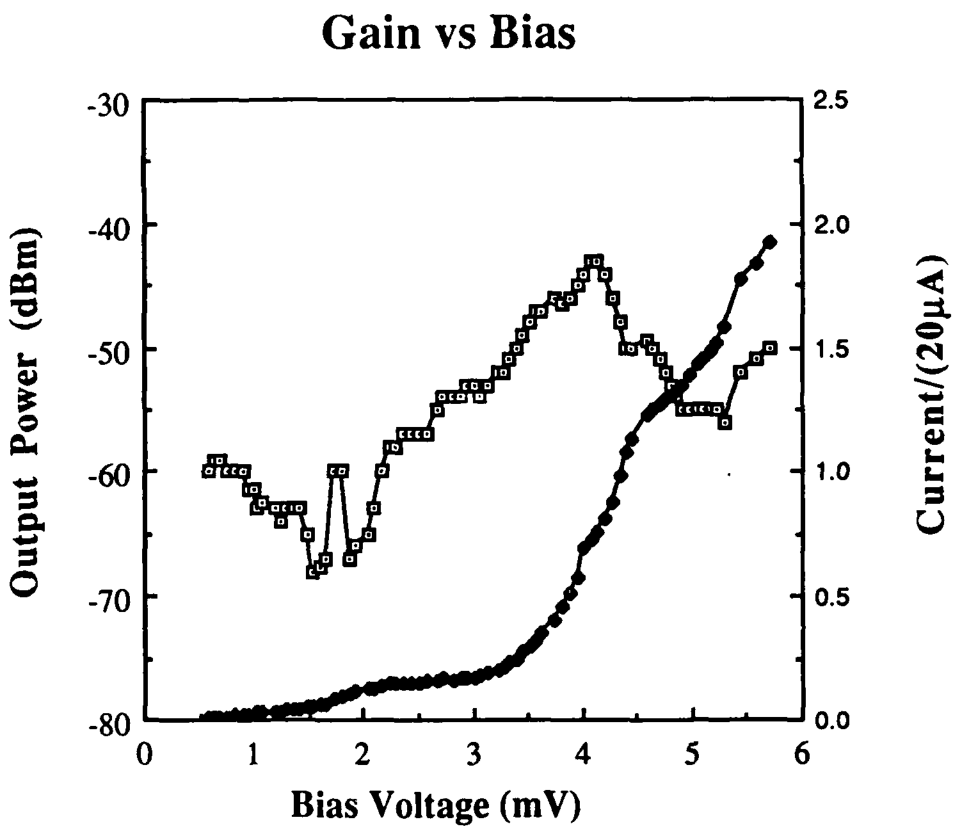
We have developed the necessary cryogenic and millimeter wave facilities to operate an SIS mixer. Our main accomplishment so far has been to demonstrate phase sensitive gain of the two-LO mixer. This demonstration was a major verification of our theory, being a test of the "noiseless" predictions of that theory.

The SIS junctions were fabricated for us by Dr. Michael Cromar at the NIST Cryoelectronics laboratory in Boulder, Colorado. We have single junctions and arrays of up to 4 junctions which were fabricated using a niobium and lead technology. The leakage current is not the best which is currently available and apparently not sufficient to reach the quantum noise limit but the work to date has been carried out with these devices and we will not seek other junctions until we are limited by the present devices.

The junction is bonded to a RF choke structure which is mounted across a waveguide. The mixer block we are using is a Niobium cavity but we have not yet added the sliding backshort and the iris coupling which we have planned. The embedding impedances were not crucial to the experiments carried out so far.

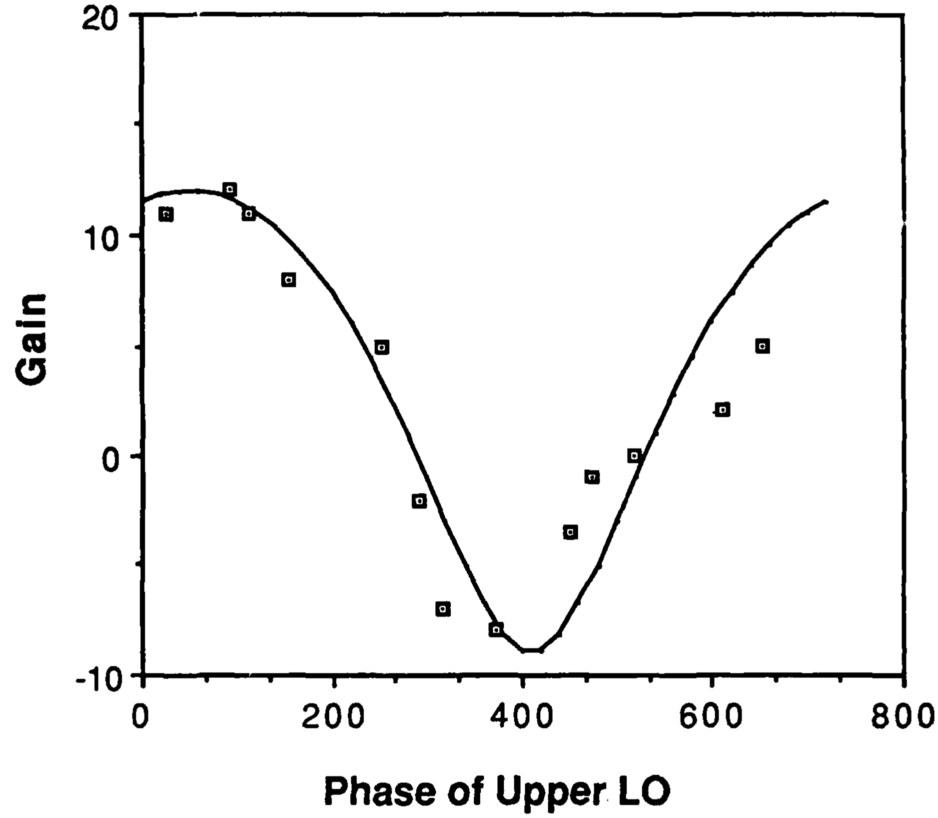
A multi-frequency microwave source was also designed. This is a Gunn oscillator and single sideband upconvertor which allows us to generate the two LO's which are at 64 and 67 GHz as well as the test signal which is at 65.5 GHz. These are all phase coherent and derive fundamentally from the same 5 MHz Quartz crystal.

In preliminary tests we demonstrated single-LO mixing. In the following figure we plot the output power of the mixer as a function of the DC junction bias. On the same graph we have superimposed the measured dc I-V curve with the LO power on. The photon steps are clearly seen in this graph and the points of maximum gain correspond to the steep parts of the photon steps as expected.




In the next figure we plot the output power of the mixer as a function of the phase of the upper LO, (@ 67 GHz). Over the range of phase shift available to us we see that the gain follows a cos($\phi$/2) dependence which is drawn as the solid curve in the figure. In this demonstration the phases of the signal and the lower frequency LO component at 64 GHz were held constant.

**Gain vs. Phase of Upper Local Oscillator**




We have demonstrated phase sensitive gain which is a major prediction of the two-LO quantum mixer theory. This increases our confidence that the theory is correct. Further experiments will test the noise predictions of the theory.

To summarize, under this contract we have investigated, both theoretically and experimentally, a new approach in the operation of SIS mixers which may allow one to circumvent the quantum noise limits of these devices. We have laid the theoretical groundwork for this genre of investigation and we have established the experimental facilities for studying SIS mixers. Phase sensitive operation of an SIS mixer was experimentally demonstrted.